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METHOD AND APPARATUS FOR STERILIZATION OF AIR IN SITES WITH LOW MICROORGANISM CONTENT

Field of the Invention

The present invention provides a process and an apparatus that enables sterilization of ventilation air necessary for sites requiring air having low microorganism content. The biological air contamination of a site is due primarily to bacteria, some of which are in the form of spores that are more resistant to relatively high temperatures. This sterilization is attained by means of a thermal process, *i.e.* by increasing the air temperature with an electrical resistor combined with the recovery of the hot air enthalpy by transfer to the cold air introduced into the apparatus from inside or outside the site. The sterile air thus obtained may be used for pressurization of a site– a hospital room, a dental clinic, *etc.* – and also to establish inside a room a sterile zone around a surgical table or a unit for processing foods or medicines.

BACKGROUND

Generally, chemical sterilization is performed using certain products, (ozone, formalin, ethylene oxide) or by means of ultraviolet irradiation. These methods are more commonly used for sterilizing instruments than for treating the large flow of air that is needed for partial or total ventilation of a site.

Generally, the air is filtered through a porous medium. The filter retains both inert solid particles and sometimes the bacteria with a size smaller than 2 μm. Filters denominated as "absolute", or high efficiency, or HEPA, have a high filtration power, sufficient to stop bacteria with dimensions of 0.3 μm. Their cost (for both initial investment and maintenance) is high and their efficiency is variable over time due to increased clogging. This cost is very sensitive to the size of the particles to be retained. Absolute filtration must always be preceded by efficient, more traditional, filtration. The efficiency of the apparatus of the present invention is independent of particle size and the apparatus is not subject to clogging, even after prolonged use. It has the potential to neutralize simultaneously bacteria, viruses, desquamated (sloughed) skin, fungi, and any solid or liquid aerosol, without requiring the efficient preliminary filtration. This is an important feature when the air being treated is to be recirculated within a site.

Furthermore, systematic measurements of the filter integrity or of the number or level of microorganisms, as a function of time, are difficult to incorporate and cannot be used for routine systematic control. A better guarantee of safety is attained through the automatic control of the sterilization temperature, which the present sterilizer permits.

Absolute filtration may be needed in large modern surgical operating rooms used for surgery of deep wounds or bones. For routine or endoscopic procedures, the extent of sterilization may be less essential.

A large array of applications exist in which thermal sterilization will be the method of choice and will allow ventilation with air pollution control at reasonable costs.

The apparatus of this invention is, in part, based on the fundamental principle of the regenerative, cyclical, and flow reversal exchanger. This principle was illustrated in: W. M. Kayes and A.L. London "Compact Heat Exchangers", 2nd Ed, McGraw-Hill, New York, 1964 (see p. 27) and also in the first edition published in 1952.

The cyclic apparatus with flow reversal has found only few applications and, to my knowledge, has never been used in the treatment of ventilation air. Exchangers with plates operating in cross-flow configuration have been preferred in spite of their lesser efficiency.

Two patents describing the use of the cyclic apparatus have been issued to the present inventor. European Patent 1,029,203 describes the use of a variant of an exchanger in the recovery of the enthalpy and the humidity of air extracted from a site and its transfer to the incoming air. This apparatus is the exact equivalent of what is known as a "double flux" ventilation apparatus with energy recovery. It includes a clean air circuit and a dirty air circuit with two tanks and two fans. European Patent 0,607,379 concerns the catalytic combustion of hydrocarbons, *i.e.* the elimination of chemical pollutants (molecules). It describes an apparatus including two stacks used for heat storage located not in two separated tanks but in a single tank which also includes the catalyst. The total pressure drop (stacks and catalyst) is fairly high, but very efficient combustion reactions and heat recovery are not required. A simplified apparatus is therefore sufficient in spite of these inefficiencies.

The design of a cyclic apparatus appropriate for the production of sterile air in the vicinity of the user, in the same room, with a very high efficiency of sterilization, of the order of 99.9%, necessitated the solution of additional important problems. The objective of this invention was to design an apparatus that would solve these problems, and simultaneously to obtain an important reduction in the apparatus volume, energy consumption, and investment cost. Consequently the present system may be installed not only at medical or dental sites, but also in private homes, schools, workshops, commercial shops and other sites. As used in the medical field, the important reduction of the noise level attained in the present apparatus allows its installation in close proximity of patients.

SUMMARY OF THE INVENTION

The invention provides an apparatus for sterilizing air in a site, comprising a cyclic heat exchanger with flow inversion for recovering at least a portion of the enthalpy necessary to raise the temperature of the ambient air to the sterilization temperature by transmission of this enthalpy to the flow of ambient air; the heat exchanger comprises two zones included in single tank which may be installed horizontally or vertically and each zone comprises a stack of metallic grilles which are arranged perpendicular to the air flow; between the two zones, *i.e.*, between the two stacks. An electrical resistance is disposed and used to provide the required electrical energy. The metallic grilles comprise wires having a diameter of between 0.1mm and 1 mm; these metallic grilles have a volumetric porosity of between 75% and 95% and consequently, the stacks of grilles have a slightly higher porosity. Each stack has a thermal conductivity which is greater in the direction perpendicular to, rather than in the direction of, the air flow. A centrifugal fan is used for circulating the air through the two stacks, once in a direction and, after a flow inversion, in the opposite direction and in both cases in a path that is perpendicular to the stacking of the grilles. A cyclic timer system is adapted, comprising two main feed valves or gates (solenoid), each valve being adapted to operate for half-cycle durations. The cyclic timer system is adapted to reverse a position at a frequency greater than once per minute.

An air filter for solid particles is disposed in the inlet of the centrifugal fan and should be of a non clogging type, of low efficiency and be easily removable.

According to the process of this invention, the air circulator is adapted to aspirate and move the ambient air through one of the main feed valves, during a half-cycle, then across a distribution chamber (plenum), then a first stack of grilles, then through the electrical resistor, then a second stack of grilles, , then through the second main feed valve, then either injected into the site, or recycled to the fan inlet, or across a third valve (a purge valve). During the following half cycle, the direction of air flow is reversed. Consequently the two main valves are maintained either in the open or closed position during a given half-cycle. The two purge valves are similarly actuated by the cyclic timer, but their opening time is in general relatively short and a function of the amount of air selected to be recycled.

In order to improve the velocity profile at the entrance of a given stack, the distribution chamber (plenum) located before the stack should have a relatively large volume, greater than or equal to the stack volume. The air contained in the plenum, as well as most of the air contained in the stack is not sterile and in the absence of if recycling (purge) at the beginning of the flow

inversion, the exit air will remain polluted, reducing the average sterilization efficiency of the apparatus. Use of the two purge-valves is one of the important features s of the invention.

Another important feature of the invention is the concurrent use of stacks of high volume, high porosity and short length, in association with a high inversion frequency. The metal of the grilles should have very high thermal conductivity (such as aluminum or copper). Even in this of case of high thermal conductivity, the effect of transverse heat conduction would be small but for the added effect of air flow cycling. When operating with cycling, there is sufficient time for the heat stored in one stack during a half-cycle to redistribute itself by conduction through the wires in the stack.

Consequently, due to the combination of the main features, the process and the apparatus of this invention fulfill the sought-after objective: efficient and low-cost sterilization of large volumes of air with a compact, standing apparatus, having a low noise level and functioning independently of operator interaction.

DESCRIPTION OF THE DRAWINGS

Figure 1 shows a schematic diagram of the purifier during a half-cycle in which the air is circulating from left to right, perpendicular to the stacking of the metallic grilles in the stacks.

Figure 2 is a schematic diagram, similar to Figure 1, showing the air circulating in the opposite direction during the subsequent half-cycle.

Figure 3 is a schematic diagram, similar to the previous figures, showing one of the purge valves in the open position in order to allow recycling of the non-sterilized air at the end of the half-cycle.

With respect to Figures 1-3, the air to be sterilized is introduced by forced circulation, in a cyclic operation, in which air flow in the first direction and its inversion (reverse air flow in the opposite direction) are controlled by means of two main-feed valves. Air flows through a thermal sterilization tank containing an electrical resistor positioned between two identical stacks of metallic grilles or screens, that are perpendicular to the air flow. The two empty zones or plenums of the chamber correspond to the two plenums for dissipating the energy of the air flow before entrance into a stack.

The air flow inversion frequency is preferably high, greater than one inversion per minute. Each cycle preferably constitutes two half-cycles of equal duration. The air that remains untreated at the end of the half cycle is recycled through the inlet of the air circulator.

DETAILED DESCRIPTION OF THE INVENTION

The apparatus comprises an air circulator (fan) (1) provided with a filter (2) adapted to eliminate dust, airborne particles, *etc.*, blows air to be sterilized coming from the outside through two main feed valves (3) and two purge valves (4) the ventilation ducts or the room itself, towards four solenoid valves. These solenoid feed valves are actuated by small electric motors or by electromagnets, activated by a cyclic timer (not represented) and well known independently of this application.

The main valves (3) allow this air flow to be introduced into either one of the two entrances of the sterilization tank in which are located the sterilization elements 7-8-9 their operation is as follows: In the position of Figure 1, corresponding to the first half of a cycle, air enters in (5) and comes out in (6). During the second half-cycle (Figure 2), after inversion of the state of the feed valves, air enters in (6) and exits in (5). References (5) and (6) designate the two empty zones or "plenums". The empty zones (5) and (6) have a volume at least equal or greater than the volume of the sterilization zones (8 and 9).

The sterilization zone between the inlets/outlets (5, 6) comprises three parts included in a single chamber (12): One element, (7), is an electric resistor placed perpendicular to the air flow and between two zones, (8 and 9), filled with stacks of metallic grilles acting as heat accumulators. The grilles in this combination, act as a cyclic heat exchanger with air flow inversion, operating by accumulation of the heat (enthalpy) from the air into the metal of the metallic grilles. This exchanger is operating in the cyclic system, *i.e.* a dynamic system known as pseudo-stationary.

The operating sequence is as shown in (Figure 1): After a preliminary period of time, the air introduced in (5) at room temperature, 25°C, is preheated in stack (8) up to about 190°C, close to the maximum temperature, then heated to 200°C (an increase of 10°C) by the electrical resistor (7), before being cooled in stack (9) to about 33°C.

After reversing the direction of the two main feed valves (3), stack (9) becomes the pre-heating stack and stack (8) becomes the cooling stack (Figure 2).

The heat input in the resistor (7) may be very small if it were possible to cool the out-flowing air at the same temperature as the inflowing air.

To obtain this efficiency, the length of the stacks should be substantial, *i.e.* to permit inclusion of a large number of metallic grilles with a very large surface for heat exchange. Clearly, this would not be economical (large volume and high pressure drop). The outlet

temperature in (6) must be higher (by 7°C in the case of information given above) than the inlet temperature in (5). The real efficiency of the heat exchanger itself is:

$$(200\text{-}33)/(200\text{-}25) = 95.4\%.$$

The enthalpy corresponding to the 10°C supplied by the electrical resistor is consumed in the loss of 7°C, *i.e.* an inefficiency exchange of 4.6% and a loss equivalent to 3°C to compensate the loss through the insulation (10).

This simplified picture of the enthalpy balance would be the same if the temperature evolution of the outflow during a half-cycle were taken into account.

The electric resistance (7) must have a relatively high surface area and be well distributed over the whole square or rectangular section of the sterilization zone in such a way as to distribute the heat as uniformly as possible. An efficient method is to use a naked nickel-chromium resistor in the form of a coiled (helicoidal) spring that traverses the section many times at equal intervals.

The starting and stabilization periods may be described in the following manner: a single electrical switch actuates simultaneously the air circulator (1), the electronic programmer (temperature controller (not represented) and the resistor (7). The maximum temperature inside the stacks (measured at a position close to the center of the apparatus) increases progressively to reach, after about sixty inversion cycles, *i.e.* about 20 minutes, the temperature selected at the design stage. A temperature controller is optional.

The pseudo-stationary system is now attained, and the performance of the apparatus remains constant as a function of time.

A main advantage of the apparatus is to minimize the energy supply to the resistor and the air circulator without raising the investment cost. To attain this goal, it has been found that the heat exchange should satisfy the following criteria:

(1) Use of metallic grilles (fabric-like wire weaves or expanded metal) presenting a high specific area (m^2 of area per m^3 of the stack). The diameter of the wires (or the equivalent diameter of the expanded metal) should be small in order to increase the heat transfer between the air and the metal. Furthermore, this large surface must correspond to a relatively large volume of the stacks, which is attained with grilles of high volumetric porosity, required for reducing the pressure drop and the fan noise level.

(2) Use of metallic grilles with a volumetric porosity between 75% and 95%, and wires of diameter between 0.1 and 1 mm are the preferred embodiment to reduce the energy requirements (resistor and air circulator/fan)

(3) High frequency of inversion, >1 cycle/ min. As an example, a for a cycle duration of 20 seconds, the air flow direction would be reversed every 10 seconds.

(4) A fourth feature is the attainment of air velocity profiles that are as flat as possible, both at the inlet and inside the two stacks. A velocity profile that is not flat is translated into the equivalent of a by-pass and consequently lowers efficiency of the heat exchanger and necessarily increases the number of grilles and the pressure drop. A fairly good air velocity profile is obtained in the following manner:

- Use of air distribution flaps extending to the depth of the apparatus with an oblique (about 45°) orientation. Preferably the cross-section of the sterilization chamber is square or rectangular and the flaps of the valves have the same length as the longest side of the cross-section. It can be seen that the flaps of the distribution valves (3) also function as deflectors allowing the distribution of air over the entire entry cross-section of the sterilization zones.

- Dissipation of the kinetic energy of the air flow in empty zones (plenums 5 and 6) of volume greater or equal to the volume of the stacks (8 and 9). (This is not shown in Figure 1 for the sake of simplification).

- The presence of the two stacks in the same chamber contributes to reducing the distortion of the air velocity profiles because the "useful" pressure drop is double and the gain obtained in one stack is transmitted to the following stack. It is well known that a higher pressure drop reduces the by-pass effect.

- Each stack (8 and 9) is preceded by a perforated plate (distributor) (11), with a large number of apertures of different diameters, the number and the size of these apertures being defined in each particular case after a study of the distribution of the air flow velocities by means of appropriated instruments (hot wire anemometer for instance). The perforated plate (11) is located between each plenum (5 or 6) and the corresponding stack (8 or 9). This perforated distribution plate serves, alternatively, as an entry into and exit from each stack and of the sterilization zone.

(5) Another essential characteristic is that the metal grilles be made of a metal of high thermal conductivity. In fact, even when criteria (1)-(4) above are met, the velocity profile will never be perfectly flat. However, it is not the goal of this sterilizer to attain such an ideal profile but rather one that is sufficiently flat to ensure that all solid particles in the aerosol (bacteria or spores) are being heated to the maximum temperature. The heat conduction along the wires of a

grille, in a permanent set-up, contributes to the flattening of the profile. However, theory and the experiments show that this contribution is small because the air crosses the full length of a stack in less than 0.1 second, a very short time for equilibration.

Fortunately, the phenomenon is rather different in the cyclic, pseudo-stationary system. For a cycle of 20 seconds (half-cycle of 10 seconds) the conduction allows the redistribution during a much longer interval (up to 100 times) given the condition, of course, that the selected metal is of high thermal conductivity as indicated in Example 2.

It is also evident that thermal conduction from one grille to its two neighboring grilles has no effect either in the permanent or the pseudo-stationary system since the conduction can only take place at a few contact points (with an equivalent area being negligible).

Another phenomenon, probably less important and very difficult to measure, is the migration paths of solid particles perpendicularly to the air flow after impacting the wires of the grilles; this aerodynamic phenomena is not amplified in the cyclic approach but it could certainly participate in reducing the by-pass effect.

The preferred metals for the grilles are aluminum, copper, galvanized steel, or stainless steel. The screens may for example be made from expanded metals of similar aerodynamic characteristics.

(6) One of the drawbacks of the cyclic system is that it is difficult to obtain a thermal efficiency over 97%. In fact, at the end of the half-cycle of Figure 1, zones 5 and 6 are cold and contain neither sterilized nor heated air. The sweeping effect from zones 6 and 9 in the following half-cycle reject this cold air that would be mixed with the subsequently arriving sterile air.

For a cycle of 20 seconds, this volume of air in the apparatus of Figure 1 is equal to 0.025 m^3 compared to 1.1 m^3 of air treated during the cycle. Therefore, on top of the loss of thermal efficiency there is a loss of 2 to 3% that could have a detrimental influence on the quality of the air produced (equivalent to a by-pass).

Operation of the apparatus with two main solenoid feed valves (3), has been described above. The incorporation of two supplementary valves (4) known as "purge valves," enables the cancellation of this by-pass. An electronic timer is used to control the opening of these valves during a predetermined time (1 second, for example) and to recycle the untreated air to the inlet of the air circulator (Figure 3). In this case sterile air is only produced for 9 seconds per half-cycle. This sweeping also affects the recycling of any microorganism that may ultimately adhere to the grilles.

The recycle ratio may be modified at will, and the sterilization efficiency can be greatly increased y multiple passes through the system.

Experiments indicate that the sterilization efficiency (disregarding the purge effect) may be much higher than the thermal efficiency. The kinetics of destruction of a microorganism is a function of the temperature and the time spent at this temperature. The function of temperature is an exponential while time has only a linear effect on the sterilization or heat transfer. The very important contribution of the exponential effect does not exist in the heat transfer. On the contrary, it contributes to the efficiency due to radial redistribution of the temperatures in the cyclic approach, with a concomitant increase of sterilization efficiency.

According to the kinetic studies available in the literature it may be estimated that a 15°C difference between two portions of the same grille would produce an increase (or a decrease) by a factor equal to 30 in the local rate of sterilization.

PROTOTYPE AND EXPERIMENTAL PROTOCOL

The tests corresponding to the three examples below were all made in the same apparatus represented in Figure 1. To facilitate the trial procedure, the air filter (2) was removed and the apparatus placed directly in a laboratory hood equipped with a HEPA filter and a laminar air flow highly superior to the apparatus air flow. The air flow in the sterilization zone was equal to 200 m^3/h and could be adjusted by modifying of the speed of the fan motor by means of a variable transformer.

The cycle duration was chosen equal to 20 seconds and the purge was active during 1 second. The two main valves (3) were inverted every 10 seconds, and the purge-valves (4) for 1 second at the beginning of each half-cycle. The flow of the sterile air actually produced is equal to180 m^3/h.

The sterilization and heat exchange zone comprised a metallic chamber made of stainless steel lamina of 0.2 mm thickness designed to reduce the longitudinal heat conduction along the walls of the chamber. Its cross-section is a 30cm x 30cm square and its length is 25 cm. The insulation of the four sides of the chamber is obtained with a rock wool mat 2.5 cm thick . Each of stacks (8) and (9) were made with 120 grilles, adjacent without compression, for a total length of 10 cm. Each grille was a square of 30cm x 30cm cut in rolls (sold by the Gantois Company). The wires of the grilles fill the entire cross-section with no discontinuity of thermal conduction.

With an air flow of 200 m^3/h, the pressure drop occurring with 240 grilles is of the order of 2 mbar (2 hectopascal). The pressure drop in the diffusers 11 is equal to 0.1 mbar. Plenums 5 and 6 have a length of 4 cm.

A resistor (7) was connected to a variable transformer and this allows the selection of the maximum sterilization temperature.

The thermal efficiency of the exchanger is calculated from the temperatures of various thermocouples installed in the apparatus.

The sterilization efficiency is measured by injecting at the air circulator inlet an aerosol containing spores of *Bacillus subtilis (Var. Niger*) that are very resistant to dry heat and are commonly utilized to test the sterility of materials after thermal treatment in a closed autoclave. This variety of *Bacillus* is not pathogenic. Various suspensions with different spore content were prepared; the liquid was pumped with a peristaltic pump equipped with a speed modulator into a sonic-atomizer of 20 kHz (Sonic Materials). The microdrops obtained, having an average diameter of 90 μm, instantaneously vaporize inside the fan, yielding a homogeneous solid aerosol in the 200 m^3/h air flow.

A biocollector SAS Super 100 was used for sampling before and after the sterilization, by impacting on agar a given quantity of air. This sterility controller was equipped with a sampling head designed for Petri dishes of 90 mm diameter. The bacillus is relatively inert. It is suggested to grow it in the culture medium tryptic soy agar (TSA) incubated at 56°C.

The samples obtained with the biocollector were sent to a private laboratory for assay (incubation and the colony determination).

EXAMPLE 1

The prototype was equipped with aluminum grilles of nominal aperture 1.4 mm and volumetric porosity = 0.875. The diameter of the wires was 0.265 mm.

After a period of 20 minutes, the pseudo-stationary state was obtained. The temperature at the entrance of the stack was equal to 25°C (including 2°C inside the fan), 190°C at the outlet of this stack and 200°C after crossing the resistor. The average temperature at the air outlet was 33°C, which corresponds to a thermal efficiency of 95.4%. The electrical energy consumed by the resistor was 0.660 Kwh/h, to which should be added 0.100 Kwh/h of the fan, which comes to a total of 0.760 Kwh for the production of 180 m^3 of sterile air. At a cost of 0.07 Euros per Kwh, the cost of operating the apparatus is about 0.04 Euros per hour.

In a typical trial, the air to be sterilized contained 1200 bacteria/m^3 or more precisely, 1200 colony-forming units (cfu)/m^3. After the sterilization treatment, the air contained 6 cfu/m^3, corresponding to a sterilization efficiency of 99.5%. The sterilization inefficiency (0.5%) is about 10 times lower than the thermal inefficiency (4.6%). The efficiency of sterilization should

increase greatly with the temperature of sterilization but the inaccuracies of the values of the cfu determination does not permit evaluation of this increase. On the contrary, the thermal efficiency is practically independent of this temperature (but the energy consumption increases slightly when the temperature increases due to the losses in the insulation.)

EXAMPLE 2

The effect of the thermal transverse conduction of the metallic wires is illustrated with this example. The origin of this phenomenon, as already mentioned, is the leveling of the temperatures in the same grille by increase in the heat transfer time (which is of the order of 10 seconds) a time much greater than the residence time of the air in the stack (0.1 second).

Three metallic grilles of the Gantois Company were compared with the use of the prototype. The three grilles (Copper, Galvanized Steel, 316 L Stainless Steel) with a nominal aperture of 1.5 mm and wires of 0.5 mm diameter, *i.e.* identical dimensions and the same volumetric porosity equal to 81%. An aluminum grille with the same characteristics is not commercially available and these grilles are not made with a nominal aperture of 1.4 mm of Example 1. The following table indicates the characteristics of the four metals (relative to stainless steel).

In the three trials of Copper, Galvanized Steel and Stainless Steel, the number of grilles were identical (60 in each stack). All the other operating conditions were equal to those of Example 1 as was the measurement of the efficiencies.

	Thermal Conductivity	Specific Heat	Specific Mass
Copper	24	0.77	1.11
Aluminum	13.6	1.9	0.34
Galvanized Steel	3.2	1.0	0.98
Reference Metal (Stainless Steel 316L)	1	1	1

The three trials have yielded the following thermal efficiencies.

Copper	0.96
Galvanized Steel	0.93
Stainless Steel	0.92

Only one factor was responsible for the higher efficiency in the copper trial: the higher thermal conductivity of the copper. The two other factors (specific heat and specific mass) were

practically equal. The inefficiency decreased from 8% (stainless steel) to 4% (copper). Aluminum should have a value practically equal to the copper.

The analysis of the temperature map at the outlet of the preheating stack showed that temperature differences as high as 15°C in the case of the stainless steel, but they were much lower with the copper grilles. Therefore a leveling effect due to the cyclic aspect is confirmed with metals of high conductivity.

The sterilization efficiencies were:

Copper	99.5%
Galvanized Steel	97%
Stainless Steel	95%

The sterilization inefficiency ratio of 10, 5% for stainless steel to 0.5% for copper, was more important than the measured thermal inefficiency ratio of 2 .

If we assume that the 15°C temperature difference is observed on a 20% portion of the flow section, and is due to a higher local air flow of 20%, a rough calculation indicates that such a by-pass could be responsible for the increase in inefficiencies by a factor equal to 8. This is based on a factor of reduction of the rate of sterilization of 30 for 15°C of temperature. These calculations are intended to be illustrative value and are approximated.

EXAMPLE 3

The purge ratio, equal to 10% in the preceding examples has an important effect on the quality of the air produced. A comparison of the performance obtained in Example 1, with those obtained without using the purge are presented below.

The two purge-valves (4) were permanently maintained in the closed position, *i.e.* in the positions of Figure 1.

The efficiency of the heat exchanger was not modified by the purge cancellation. At the end of the preheating zone, the air volume in the zones 5 and 8 (or 6 and 9) was equal to 0.0125 m^3, equivalent to 0.025 m^3 for a full cycle of 20 seconds and an air flow of 1.11 m^3 per cycle. In principle a purging time of 0.125 sec. at each valve (4) would be sufficient to eliminate the untreated air (*i.e.* 2.25%.) The global inefficiency of the sterilizer of Example 1 is now equal to:

$$0.9775 \text{ x } 0.005 + 0.0225 \text{ x } 1 = 0.0274.$$

This is an increase by a factor of 5.5 compared to Example 1.

It is not necessary to use a purge ratio as high as 10% but it should in any case be higher than 5% to compensate for mixing problems in the purge circuit and to increase the elimination

of certain solid particles sticking to the cold grilles. This loss of efficiency due to this "external" by-pass cannot be compensated by modification of the uniformity of the velocity profile or the leveling of temperatures by the conduction effect, and even less by using a larger number of grilles or by increasing the sterilization temperature. The use of the purge is then required unless a real "external" recycle from the room being decontaminated is preferred.

On the contrary, the influence of the "internal" by-pass described in Example 2 may be reduced by increasing the number of grilles and the sterilization temperature.